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DREDGED GRAVELS FROM THE CENTRAL ARCTIC OCEAN

by

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Abstract

A series of nine bottom trawls was made in the Arctic Ocean from Drifting Station Alpha. The trawls were taken in the area between 84° and 85°N and between 138° and 152°W. All the trawls produced high percentages of gravel. Macroscopic and microscopic analyses showed these gravels to be predominantly sedimentary rocks, few igneous or metamorphic specimens were found. One fossiliferous sandstone specimen is Permocarboniferous in age. Bottom cores contained similar pebbles at depths in the sediment of up to 115 cm below the bottom. Studies of the striation, roundness and shape of the pebbles reveal them to be typically glacial material which has undergone little or no water transport.

It is concluded that these gravels have been rafted by ice from a shore containing active glaciers. Considerations of Arctic Ocean circulation, Pleistocene glaciation and lithology make it probable that the source area was Axel Heiberg Island, Ellesmere Island or the northern coast of Greenland.

***

Drifting Station Alpha was organized and maintained as a scientific research station on an ice floe in the central Arctic Ocean by the combined efforts of the U. S. National Committee of the International Geophysical Year and the United States Air Force.

The station was in operation from April 1957 to November 1958. Lamont Geological Observatory of Columbia University carried out a program of marine geophysics at the station under contract AF 19 (604) 2030 from Air Force Cambridge Research Center. One aspect of the marine geophysics work was the study of the ocean floor. A winch and cable allowed oceanographic gear to be operated in the same way as on board a research vessel. A total of 9 dredge samples, 14 bottom cores and about 200 bottom photographs were obtained from the station. The most remarkable feature of sedimentation revealed by these investigations is the high percentage of gravels and sands on the ocean floor. The relative density of such gravels is most impressively seen in bottom photographs (Plate 1) (Hunkins, et al, in press). This coarse material has undoubtedly been ice-rafted and dropped to its present position.

Most of the gravel samples were taken with a small bottom trawl consisting of a net held in place by a steel frame. The mouth opening was 10 x 100 cm and the net had a mesh of 0.5 mm. In operation, the trawl was lowered until a decrease of tension on the dynamometer indicated bottom contact. Some extra cable was then payed out and the trawl was towed by the drifting ice floe for a period of from 1 to 4 hours. The actual distance traveled by the trawl on the bottom was from about 1000 feet to one mile. One sample was also obtained with a bucket dredge and another with an Ekman grab. One rock was brought up accidentally

when it wedged itself into a sprocket wheel used as a weight during other operations. Material collected by these methods represents, of course, only the topmost layers of sediment. Information on the various samples is given in Table I.

The samples consisted generally of one to four liters of brown mud mixed with various amounts of sand and gravel. Since the mesh of the dredge net was 0.5 mm, the samples faithfully represent the bottom sediment only for particle sizes greater than this. The smaller fractions are best examined from core samples where they are seen to be partly normal marine sediment and partly glacial marine sediment. All dredge samples were washed and only the fraction larger than three mm. was examined in detail.

After sieving the samples, the fraction greater than 3 mm was examined under the binocular microscope. Sandstone, shale, metamorphic and igneous rock types were separated by inspection, limestones and dolomites were differentiated by staining with alizarine red S (Friedman, 1959). Gravels larger than 20 mm were thin-sectioned and examined under the polarizing microscope.

The composition of the various sieve fractions seems to change with some regularity. Especially notable is the increase of shale and sandstone in the fraction less than four mm and the maximum occurrence of dolomite in the fraction between four and ten mm. It appears that the size is determined to a degree by the rock type.

TABLE I

Sample No.	Position Lat.	Long.	Depth Sounding	Gear Used	Period of Dredging	Date
1	83° 59'N	151° 44'W	2590m	Bucket dredge		27 April, 1958
2	84° 09'	150° 23'	2490	Bottom trawl	1 hr.	8 June, 1958
3	84° 16'	149° 11'	1658	Bottom trawl	1 hr.	12 June, 1958
4	84° 22'	148° 51'	1776	Ekman grab	-	14 June, 1958
5	84° 27'	148° 28'	1700	Bottom trawl	1 hr. 50 min.	16 June,1958
6	84° 33'	146° 24'	2201	Bottom trawl	1 hr. 30 min.	7 July, 1958
7	84° 30'	145° 00'	2294	Bottom trawl	1 hr. 45 min.	9 July, 1958
8	84° 31'	143° 30'	2118	Accidental catch	-	11 July, 1958
9	85° 01'	138° 00'	1840-1910	Bottom trawl	4 hr. 15 min.	31 July, 1958

In the following descriptions the weight percentages of the different rock types in the material greater than 3 mm are given. The gravels with a diameter greater than 20 mm are described in some detail. Since a definite source area has not yet been located for these samples, it is hoped that these descriptions may lead to a more positive identification of their source.

<u>Sample 1</u> Fraction greater than 3 mm. 135 gms.

No pebbles greater than 20 mm.

Limestone......................	15%
Dolomite.......................	26%
Sandstone and Shale..............	50%
Igneous and Metamorphic.........	9%

<u>Sample 2</u> Fraction greater than 3 mm. 1029 gms.

Fraction greater than 20 mm. 253 gms.

Limestone......................	32%
Dolomite.......................	36%
Sandstone and Shale..............	27%
Igneous and Metamorphic.........	5%

The <u>limestone</u> in this sample is all of the same type. In hand specimen it is light gray to blue gray. Under the microscope it is a true calcilutite with some patches of coarser recrystallized calcite mosaic. Shell fragments and occasional crinoid ossicles occur but

they constitute only a small proportion of the rock. Specks of limonite after pyrite are seen in some sections.

The dolomite in all the dredge samples appears to be of the same type. It is either white or white-brown and is invariably recrystallized into a dolomite marble with crystal sizes of 0.01 to 0.5 mm. The crystals occur in a mosaic in which rhombic crystal shapes are rarely seen. In two specimens a preferred orientation of the fabric was noted, suggesting that the rock has undergone some tectonic deformation. In some of the dolomites, a slight grading of the grains produces a lamination of 0.5 to 1.0 mm thick. Occasional small unconformities occur within the laminae and in one instance small scale channeling is well developed. Clastic quartz grains may be interspersed in the dolomite or occur as small lenses of sandstone. The quartz grains are sub-angular with grain diameters raning from 0.04 to 0.06 mm. Fossil remains are rare and unidentifiable. It is likely that these dolomites are derived from an extensive series which was deposited under shallow water conditions and which may have been interbedded with sandstones.

In this sample, only one sandstone pebble is found. It is a dark gray, greywacke type with angular quartz grains of 0.01 to 0.05 mm diameter in fine-grained cement of mica and chlorite. The quartz grains show signs of strain.

Only one metamorphic pebble was found in this sample, a chloritoid schist. It is a fine-grained quartz mica schist containing porphyroblasts of chloritoid and sharply defined patches of calcite.

<u>Sample 3</u> Fraction greater than 3 mm. 30 gms.

No pebbles greater than 20 mm.

Limestone	13%
Dolomite	29%
Sandstone and Shale	43%
Igneous and Metamorphic	15%

<u>Sample 4</u> Fraction greater than 3 mm. 23 gms.

No pebbles greater than 20 mm.

Limestone	21%
Dolomite	22%
Sandstone and Shale	44%
Igneous and Metamorphic	13%

<u>Sample 5</u> Fraction greater than 3 mm. 3307 gms.

Pebbles greater than 20 mm. 2698 gms.

Limestone	11%
Dolomite	33%
Sandstone and Shale	54%
Igneous and Metamorphic	2%

One <u>limestone</u> pebble is light gray to yellow and contains a large number of shell fragments in a calcilutite matrix. Among others, fragments of pseudopunctate brachiopods, tentatively identified as

chonetids and productids are present. In addition, shells of gastropods, crinoid ossicles and some bryozoans are seen. The limestone is probably Permocarboniferous in age. Dolomites are as described in sample two.

One large sandstone specimen with a calcareous cement is present. The quartz grains are subangular, ranging from 0.02 to 0.1 mm in diameter. The cement is recrystallized and large areas show common extinction. This specimen is highly fossiliferous. The following brachiopods have been identified by Professor A. Williams:

Lingula sp.

Neospirifer sp.

Spiriferina sp.

Aulosteges sp.

Chonetid

The following bryozoans have been identified by Dr. R. S. Boardman:

Rhombotrypella sp.

Rhabdomeson sp.

Polypora sp. (?)

In addition to these, crinoid ossicles and gastropods also occur. Both the brachiopods and bryozoans indicate a Permocarboniferous age, more likely Permian.

One large greywacke type sandstone is dark green with black shale wisps parallel to the bedding plane. Quartz grains are very well-rounded with diameters from 0.02 to 0.3 mm. Many of the quartz grains show

well-developed strain lamellae and the mica matrix exhibits "flow structure" deformation. Low grade metamorphism is likely. Another similar sandstone pebble is more metamorphosed with interpenetrating grain boundaries.

Three sandstone specimens, with a relatively unaltered appearance, vary in color from yellow to dark brown and are cemented with carbonate. Only one, which contains a fair amount of bitumen and some unidentifiable organic remains, is distinctive.

One conglomerate is found. Well-rounded pebbles of dark gray to black chert and a few quartzite pebbles occur in a matrix of quartz sandstone and chert. The chert is recrystallized and contains no organic remains.

In sample five, one loose piece of chert is found. It contains a large amount of calcareous organic detritus and some rare quartz grains. Noteworthy are several glauconite grains. The quartz grains have an average diameter of 0.05 mm.

Sample 6 Fraction greater than 3 mm 93 gms.

No pebbles greater than 20 mm.

Limestone	14%
Dolomite	42%
Sandstone and Shale	36%
Igneous and Metamorphic	8%

Sample 7 Fraction greater than 3 mm. 156 gms.

No pebbles greater than 20 mm.

Limestone	16%
Dolomite	45%
Sandstone and Shale	35%
Igneous and Metamorphic	4%

Sample 8

This sample contains only one dolomite pebble which weighs 103 gms. It is the same type as the dolomite described in sample two.

Sample 9 Fraction greater than 3 mm. 8739 gms

Pebbles greater than 20 mm 8692 gms.

Limestone	8%
Dolomite	5%
Sandstone and Shale	3%
Igneous and Metamorphic	84%

One yellow-gray limestone is found which is unlike any previous type. It is a calcilutite with some small recrystallized areas. It contains many poorly preserved fossils, probably brachiopod shells and foraminiferal tests. A few pyrite crystals are present. Small limestone mud pebbles in this limestone suggest shallow water conditions for its formation. A second limestone pebble is dark gray in color with a pellet texture. A few quartz grains (0.02 to 0.04 mm.) are interspersed in it.

One large dolomite pebble of the same composition as those in sample two is found.

A pink sandstone specimen consists of close-fitting, well-rounded quartz grains with diameters of 0.1 to 0.3 mm. It is cemented with calcite.

One diabase cobble weighing 7300 gms forms the largest part of this sample and greatly affects the percentage composition. Under the microscope it is seen to consist of a large mass of lath-shaped feldspars with a labradorite to andesine composition. Large plates of pyroxene are in oophitic intergrowth with the feldspar. Some skeletal crystals of magnetite are present. Marginal to the pyroxenes and in the mesostases small amounts of amphibole are seen. Some quartz occurs in rounded, slightly corroded, grains.

In addition to the above described material, pebbles were also found at various depths in the core samples. The cores were taken with a small Ewing piston corer having a diameter of 1-1/2 inches. A full description of these cores will be published later. In many respects these pebbles resemble those dredged from the top layer of sediment. They are generally small, the largest being 17 mm. in diameter.

Core 2 was taken at 83° 52'N 168° 12'W at a depth of 1521 meters. One small pebble of a basic igneous rock was found at a depth of 115 cm in the core.

<u>Core 4</u> was taken at 84° 21'N, 168° 49'W at a depth of 2041 m. One piece of cericite schist was found at 46 cm.

<u>Core 5</u> was taken at 84° 28'N, 169° 04'W in 1934 meters of water. A light gray limestone with some shell fragments (brachiopods?) was found at 46 cm in the core.

<u>Core 10</u> was taken at 84° 19'N, 166° 50'W in 2418 meters of water. A dolomite pebble similar to those in the dredge samples was found at 64 cm.

<u>Core 15</u> was taken at 84° 10'N, 149° 40'W in 2045 meters of water. A fine-grained sandstone pebble was found at 69 cm.

Many of the dredged rocks are partly covered with a thin black manganese coating. It is found on all of the specimens larger than 20 mm. and on a large number of the smaller pebbles. The layer of manganese is extremely thin, probably less than 0.001 mm. It is restricted to the part of the pebble which was exposed to the sea water. The portion immersed in mud is not coated. If the specimens are oriented into their original position as indicated by the boundary of the coating, the average ratio for 18 pebbles of the depth of the submerged portion to the height of the emerged portion is about 1:3. This ratio does not correlate with rock size. It is interesting that this manganese coating occurs in a similar fashion on the pebbles from cores, showing that they too were at one time exposed to sea water. Many of the dredged rocks also carry encrusting worm tubes on the manganese-coated portion.

However, no living specimens were found in any of the worm tubes and the tubes themselves are in many cases coated with manganese (Plate 2).

Surface Texture and Roundness

Nearly half of the 27 rocks larger than 20 mm in diameter show a distinct glacial striation. Wentworth (1936a) finds a similar proportion of striated rocks in moraine deposits. As expected, limestones usually preserve the best striations. Striations on dolomites are relatively short, coarse and poorly preserved. Some of the limestone pebbles show a high degree of polish. Cellulose peels of these surfaces have been made and examined under the microscope. The polish is seen to be abrasive and contains many minute scratches in the direction of the large striae. The cellulose peel technique proved valuable in examining all types of striations (Plate 3).

The general shapes of the pebbles have been classified using the system of Wentworth (1936a) and the results, together with the striation data, are summarized in Table 2.

Wentworth (1936b) finds that the characteristic shape of the glacial pebble is the pentagonal outline, flatiron stone. This shape accounts for 26% of the above sample. In contrast to this, pebbles shaped in ice jams of periglacial rivers are essentially river pebbles on which striations are only superimposed. Snub scars are absent and are replaced by short broad bruises. The parallelism of the direction of striae to the longest axis of the

TABLE 2

CHARACTERISTICS OF 27 PEBBLES GREATER THAN 20 MM DIAMETER

Striation

Occurrence	Present	Subparallel to longest axis	Parallel to longest axis	Irregular
No. of Pebbles	10	8	7	3

Snubscars

Occurrence	Present	Marked
No. of Pebbles	7	3

Outline of Maximum Projection Area

Shape	Triang.	Quadr.	Rect.	Trapez.	Pentag.	Polyg.
No. of Pebbles	3	4	3	6	7	4

***

pebble is less common. Irregular striation patterns occur more frequently than on glacial pebbles.

A number of authors have used the study of particle roundness for reconstructing the history of a sediment. Unfortunately a large number of factors influence rounding and there are always two unknown quantities present: the environment in which rounding took place, and the length of time which the sediment was exposed to that environment. Further complications are presented by the use of several different roundness coefficients (Krumbein and Pettijohn, 1938).

The sizes from 2 to 10 mm were chosen for roundness measurements. From each dredge sample 25 limestone and 25 dolomite pebbles were selected. Drawings of the maximum projection area were made by enlarging the grains through projection to a standard diameter of 7 cm. The Cailleux index was determined for all samples. This index was chosen since there are more data for comparison expressed in it than in any other.

Most water transported sediments show a relationship between the size of the pebbles and their roundness and thus only pebbles of one size group are strictly comparable. Whether a similar relation exists for glacial material is not known. A comparison of three subsamples of 25 dolomite pebbles each from dredge number 2 gave 0.112 for the 3-5.4 mm fraction, 0.108 for the 7-11 mm fraction, and 0.101 for the 20-100 mm fraction. The apparent decrease of roundness with the larger sizes is not statistically significant. A comparison between the dolomite and limestone pebbles was also made. They showed no significant difference in roundness. Table 3 gives the roundness for the dredged material in the 3-5.4 mm range and the average for all pebbles greater than 20 mm.

The roundness of the Station Alpha material agrees well with the roundness of tills as found by various authors. Van Andel (1954) found a mean Cailleux index of 0.085 with a standard deviation of 0.059. Tricart

TABLE 3

Dredge No.	Size Range	Mean Cailleux Index	Standard Deviation	Sample Size
2	3-5.4 mm	0.112	0.056	50
3	"	.128	.064	50
4	"	.116	.036	50
5	"	.128	.064	50
6	"	.112	.044	50
7	"	.124	.051	50
8	"	.112	.056	50
All pebbles	20 mm	.101	.052	27

***

and Schaeffer (1950) found a range of 0.100 to 0.150 and Cailleux (1952) found a range of 0.040 to 0.190.

Although the cores yielded only five pebbles for examination, these too appear to be of glacial origin. Striae are well developed on one of the pebbles and all seem to have the same degree of roundness as the dredge samples.

Conclusions

From the examination of the roundness, shape and striae of these gravels, it is apparent that they are of glacial origin. It is also evident that this material has undergone little if any transport by water.

Kuenen (1956) carried out experiments on angular sandstones from solifluction material with an average roundness of 0.044 and found that, afteronly 0.4 km of transport, the roundness increased to 0.113 and, after 3 km, to 0.275.

Observations by Wentworth (1922) showed that a travel distance of only 0.35 miles was sufficient to remove striae from hard limestones and greenstones. It thus appears that these gravels have been ice rafted from a coast on which active glaciers reached the shore. It is probable that transport was in icebergs which calved directly from the glaciers. Also at least part of the material was frozen into the bottom of either grounded icebergs or sea ice. Clarke (1959) has studied the molluscan shells from the described dredge samples and concludes since they are shallow water species, that many of the shells have been transported to their deep water locations. They surely must have been picked up by grounded ice in shallow water near shore.

The known Arctic Ocean circulation in this area (Worthington, 1959; Browne and Crary, 1959) and the extent of Pleistocene glaciation (Glacial Map of Canada, 1958) limit considerably the possible source areas for these gravels. The circulation pattern in the North Canadian Basin makes it likely that the material was obtained from the northern coast of Greenland, the Canadian Arctic Archipelago or the northern coast of Alaska. Since the northern coast of Alaska and most of the northern Canadian islands are believed to have been unglaciated during

Pleistocene time, we are limited to Axel Heiberg, Ellesmere Island and the northern coast of Greenland as a source area.

Two features of the gravel composition tend to support this source area. One sandstone specimen has been definitely identified as Permo-carboniferous. Strata of this same age are found on Axel Heiberg and Ellesmere Island and on northern Greenland (Geol. Map of North America, 1946; Geol. Map of Canada, 1945). In addition, all Station Alpha dredge samples contained a characteristic white dolomite marble which may be identical with the dolomite of pre-Cambrian to Cambrian age found in these same areas (Armstrong, 1947). In the future, comparison of the gravels with actual samples from the arctic coast may provide more positive identification of the source area.

A comparison of the Station Alpha data with the Russian NP-2 data (1954-1955) shows that the composition of the gravels in this basin of the Arctic Ocean is fairly uniform. The Russian dredge stations were taken at a distance of from 200 to 600 miles from those of Station Alpha.

Figures 1 and 2 show the relative composition of the Station Alpha gravels in comparison with those of Russian NP 2. A plot (Fig. 1) of the three components, clastic-carbonate-igneous, reveals a close similarity between the sediments of the two stations. Agreement is not quite so good in Figure 2 where limestones, dolomites and clastics have been plotted. No agreement is seen between the dredged gravels found by Station Alpha and NP-2 and the rocks on the surface of T-3, Fletcher's Ice Island,

TABLE 4

RUSSIAN DREDGE STATIONS - NP-2 (1950-51)

Station No.	Lat.	Long.	Depth
1	76° 23'N	177° 49'W	1239m
2	77° 44'	171° 18'	2245
3	77° 13'	168° 49'	542
4	78° 24'	168° 11'	512
5	78° 48'	170° 52'	2788
6	78° 51'	166° 03'	1435
7	78° 55'	162° 58'	836
8	80° 36'	160° 25'	2861
9	80° 39'	164° 01'	3047
10	80° 48'	162° 58'	3266
11	80° 48'	161° 48'	3622

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where mainly schists and gneisses were found with a noticeable absence of limestone and other sedimentary rocks (Shorey, 1953; Stoiber, et al, 1956).

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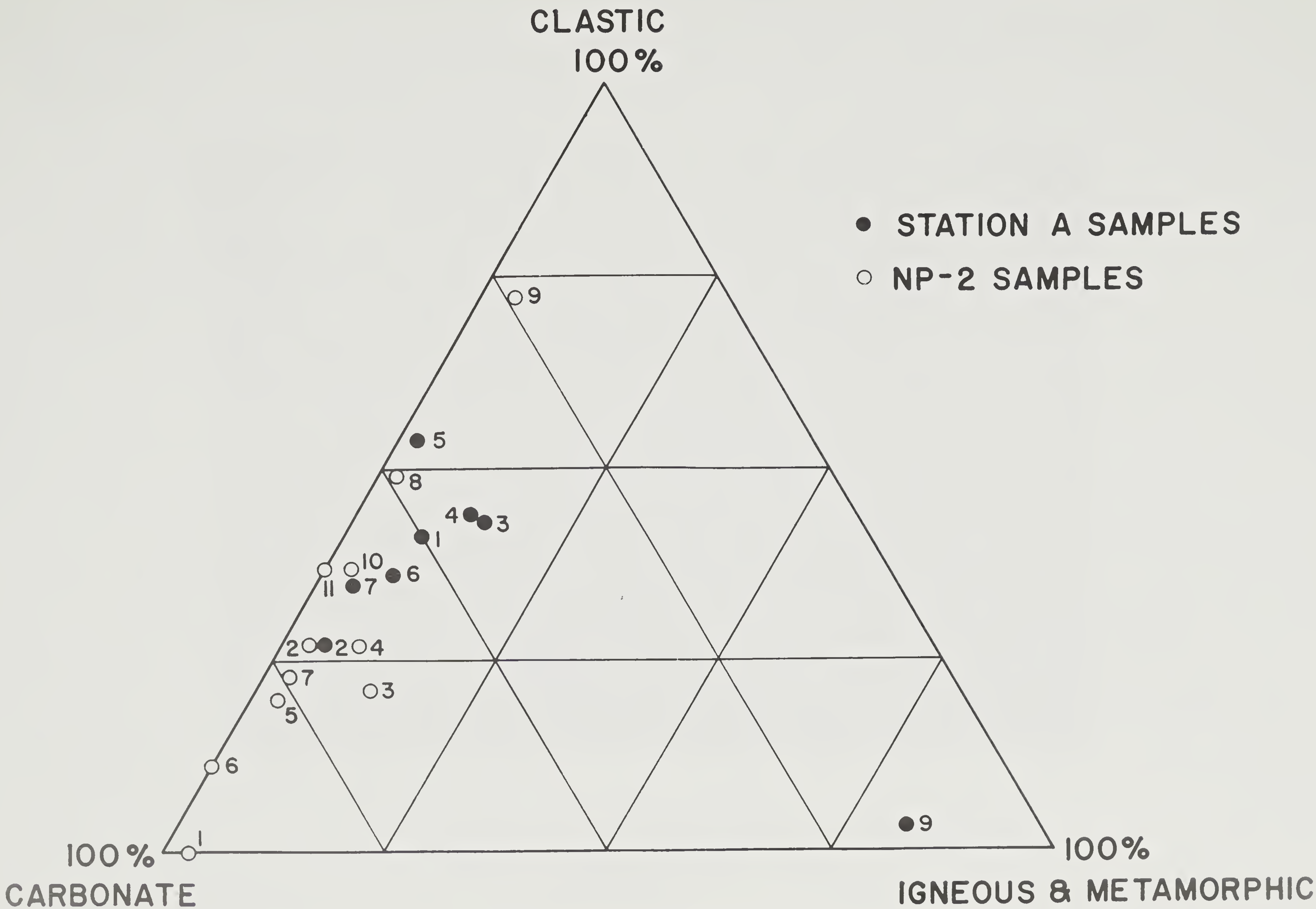

Figure 1 Carbonate-igneous-clastic composition of Station Alpha and Russian NP-2 samples

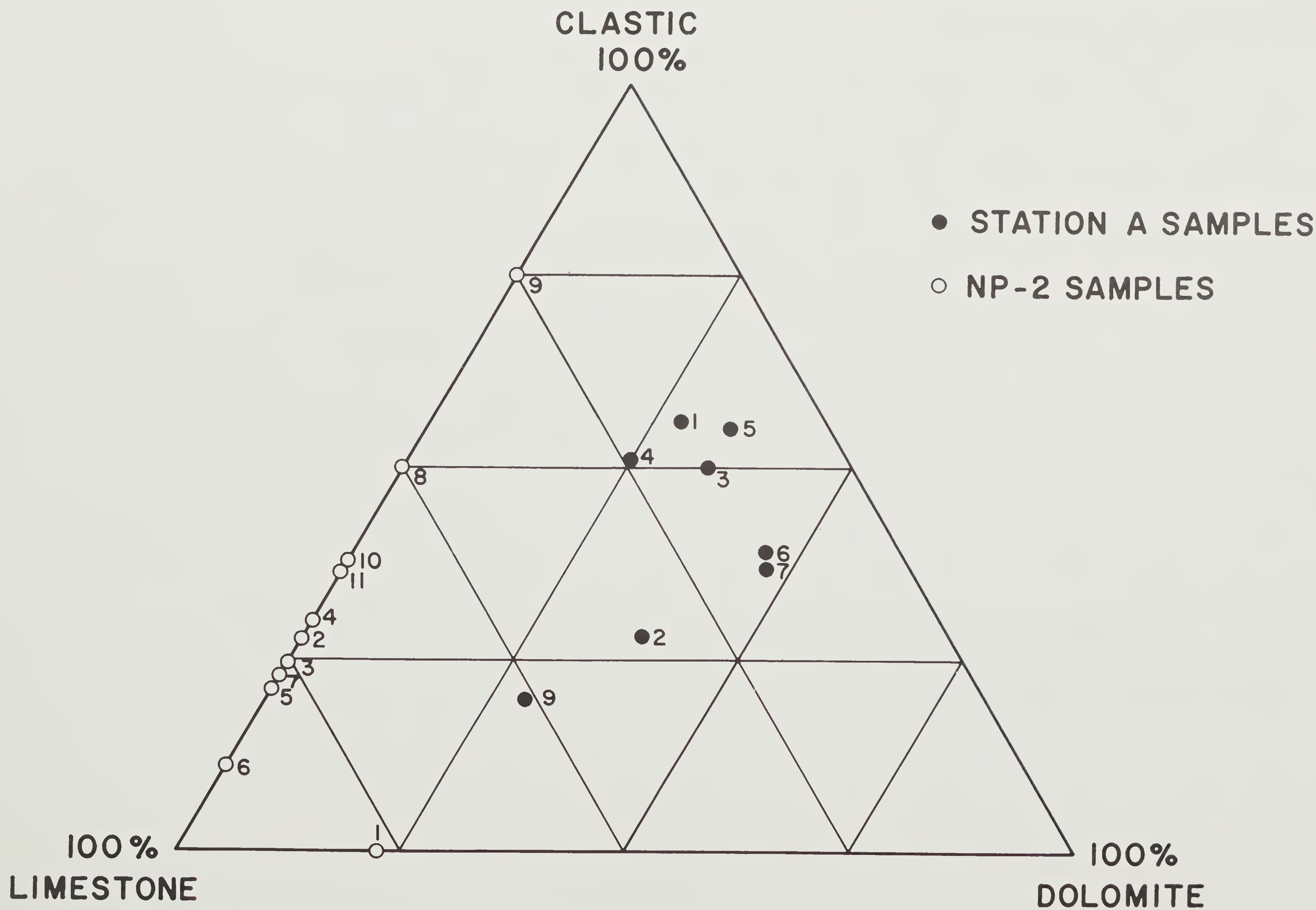

Figure 2 Limestone-dolomite-clastic composition of Station Alpha and Russian NP-2 samples

Plate 1 Bottom photograph taken at 83° 35'N, 162° 30'W in 2400 meters of water. The area included in the picture is about one square meter.

Plate 2 Rock specimens from dredge 6.

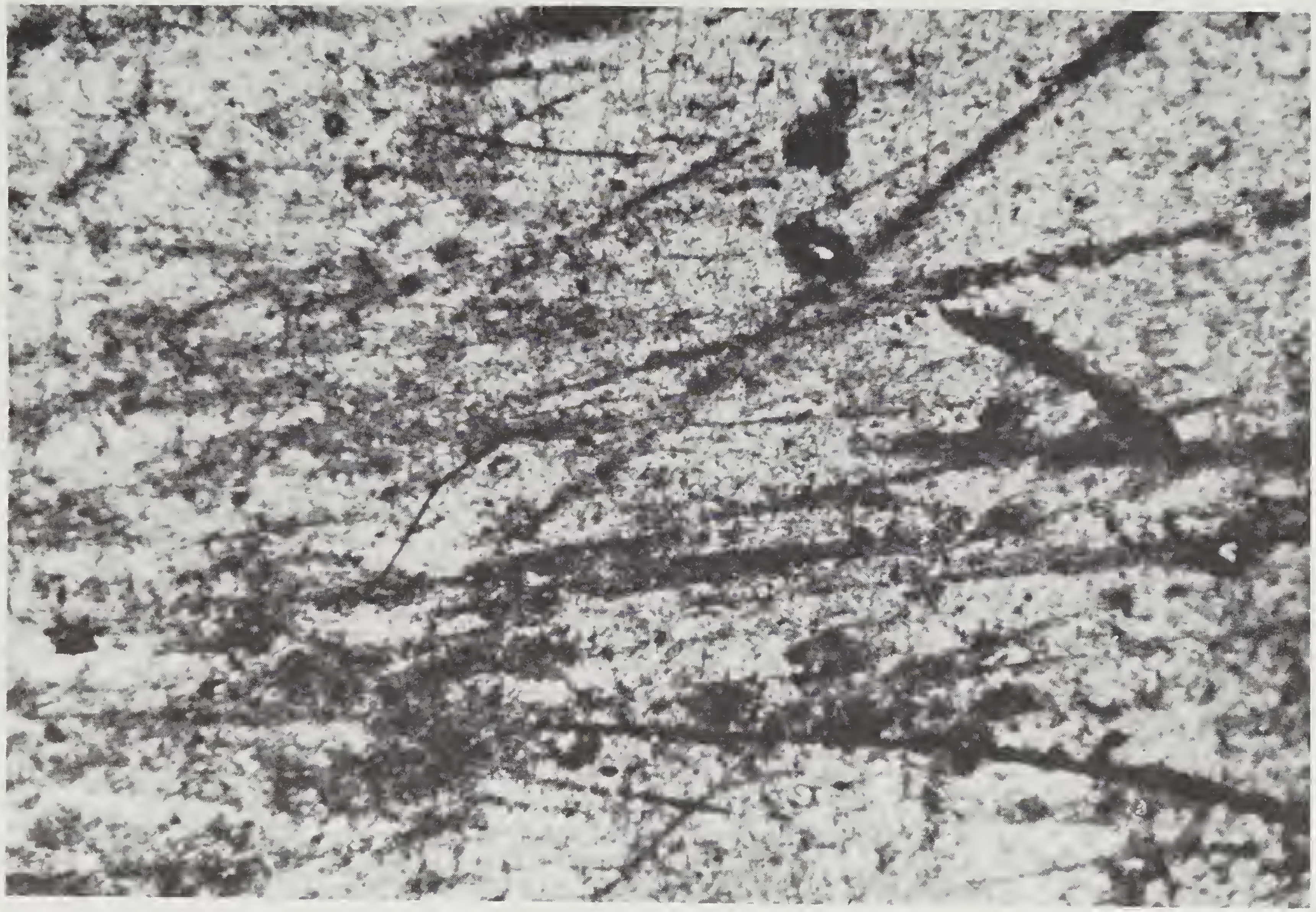

Plate 3 Cellulose peel from rock specimen showing subparallel striations. Enlargement 425 times.